

# Source Ambiguities for Imaging and Interferometric SAR

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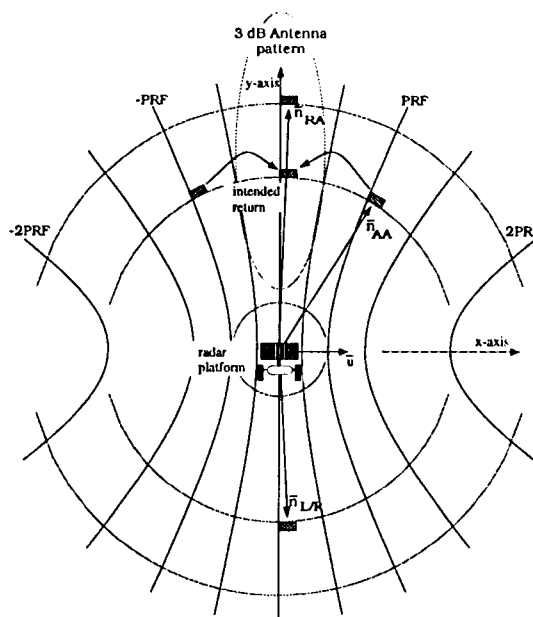
## ABSTRACT

One of the greatest costs of any spaceborne mission is the total instrument mass. For SAR, one third of the mass is typically related to the antenna structure, whose elevation and azimuth dimensions are used to increase the signal to noise ratio as well as to reduce the presence of spurious signals.

As the wavelength increases, so too does the antenna dimensions to achieve equivalent performance. Thus, the antenna for a P-band mission is likely to be several times larger than that for, say, an L-band, mission. The L-band antennas for SIR-C and JERS-1 for example are on the order of 12m in azimuth and 3/2.5 meters in elevation. An equivalent P-band antenna would be more than three times larger (but, as will be shown, not necessarily in the azimuth dimension). Understanding the tradeoffs between signal to noise ratio, ambiguous sources and the antenna dimensions is a key to producing a cost effective low frequency mission design. In this short paper, we focus on the presence of source ambiguities, or those spurious signals arising from ground targets which are imaged concurrently with the intended target.

## INTRODUCTION

Source ambiguities are defined as SAR noise sources inherent to the observing geometry and are directly related to physical targets on the ground. There are three principal types of source ambiguities, these are: 1.) range, 2.) wrong-side and 3.) azimuth. For low frequency SAR, the first two of these can be particularly problematic because of the difficulty in constructing antennas of sufficient size to achieve the directivity required to reduce the presence of those ambiguities.



**Figure 1.** Planimetric location of first order ambiguous sources.

For imaging or polarimetric SAR the ambiguities have the effect of aliasing the observed backscatter return for a particular pixel. Additionally, because the ambiguities are associated with a physical source on the ground, the signal remains correlated between looks, thus multilook averaging serves only to smear out strong noise sources over neighboring pixels. Source ambiguities for interferometric SAR pose an alternate problem. While the imaging SAR ambiguities still remain, their effect on the differential phase measured by a radar interferometer can be treated as a separate issue. This analysis relates directly to the height accuracy over which the interferometer attains, whereby it can be shown that most source ambiguities are not correlated between the interferometric pair and thus can be mitigated by multilook averaging.

## GEOMETRY

Knowing the physical location of ambiguities and understanding their source, is an important step in reducing their effect on the final product. As a general rule, ambiguities arise from a mathematically equivalent solution for the location of the intended target. Both range and wrong-side (L/R or Left/Right) ambiguities are directly related to the observing geometry, while azimuth ambiguities are due to an undersampling of the doppler spectrum [1]. The location of each of the ambiguities is given by

$$\begin{aligned}\bar{n}_{RA} &= H \left[ \left( \frac{nc}{2H \cdot PRF} + \frac{1}{\cos^2 \theta} \right)^2 - 1 \right]^{1/2} \hat{y} - H\hat{z} \\ &= \cos^{-1} \left[ \frac{1}{nc / (2H \cdot PRF) + 1 / \cos \theta} \right] \hat{\theta}\end{aligned}\quad (1)$$

for range ambiguities ( $n$  is the ambiguity number),

$$\begin{aligned}\bar{n}_{L/R} &= -H \tan(\theta - 2\alpha) [\hat{y} + (1 + \tan \alpha) \hat{z}] \\ &= (-\theta + 2\alpha) \hat{\theta}\end{aligned}\quad (2)$$

for wrong-side ambiguities (where  $\alpha$  is the ground slope angle), and

$$\begin{aligned}\bar{n}_{AA} &= \frac{-\lambda PRF}{2u} \hat{x} + \left[ R^2 - H^2 - \frac{\lambda^2 R^2 PRF^2}{4u^2} \right]^{1/2} \hat{y} \\ &\approx \theta \hat{\theta} - \tan^{-1} \left[ \frac{\lambda PRF}{2uH} \right] \hat{\phi}\end{aligned}\quad (3)$$

for azimuth ambiguities. In the above,  $R$  is the range to target,  $H$  is the platform height,  $\lambda$  is the wavelength and  $PRF$  is the pulse repetition frequency, all referenced to the platform position (see Figure 1).

The physical aperture of a SAR is used to attenuate the signal contribution each of these sources. Range and wrong-side ambiguities scale directly with frequency, whereas azimuth ambiguities do not. This has the effect of increasing the elevation dimension of the aperture but not the azimuth dimension as frequency is decreased.

## IMPACT ON IMAGING AND INTERFEROMETRIC SAR

The signal to noise ratio for imaging SAR can be calculated directly from the antenna pattern for range and wrong-side ambiguities or by an integral equation [2] for azimuth ambiguities (see Figure 2).

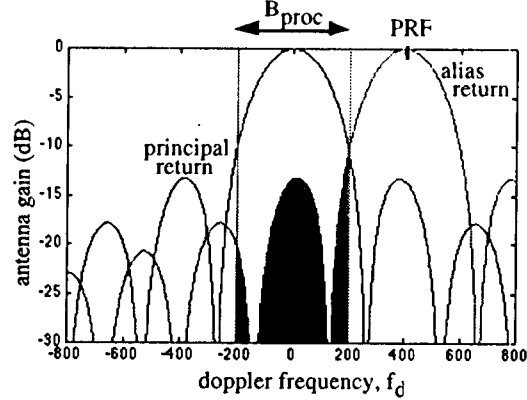


Figure 2. Calculation of azimuth ambiguity SNR.

For interferometric SAR we are interested in the phase bias that the ambiguous sources will introduce into the signal (which will directly translate into a height error). For a phase bias to be introduced, ambiguous returns from both antennas of the interferometric pair must be coincident, so that their net phase difference is correlated (i.e. has a non-zero expected value). Otherwise, the effect of phase noise may be reduced by multilook averaging.

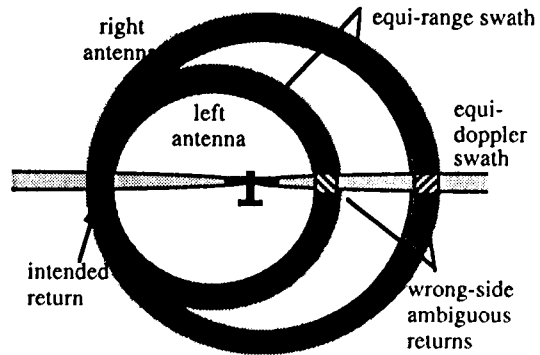


Figure 3. Location of wrong-side ambiguities for an interferometric pair.

For the three types of source ambiguities, the ground separation,  $\delta$ , is

$$\bar{\delta}_{RA} = 0, \quad \bar{\delta}_{L/R} = 2B \cos \xi \quad (4,5)$$

$$\bar{\delta}_{AA} = B \cos \xi \sin \theta \left[ -\frac{\lambda PRF}{2u} \hat{x} + \left( \frac{\lambda^2 PRF^2}{8u^2} + \frac{\cos^2 \theta}{2} - 1 \right) \hat{y} \right] \quad (6)$$

where  $B$  is the baseline length and  $\xi$  the baseline tilt angle. Equations (4) through (6) can be used for estimating the decorrelation (due to misregistration) of the noise sources which can then be translated into a height error estimate via [3]

$$\sigma_h = \frac{1}{\sqrt{2N}} \frac{\sqrt{1-\gamma^2}}{\gamma} \quad (7)$$

The impact of (4) through (7) is that the impact of most source ambiguities can be mitigated by multilook averaging. In this manner, an engineering tradeoff can be made between resolution and height accuracy for the problem of ambiguous sources.

### ALTERNATIVE METHODOLOGIES

As implied in (1) through (3), the impact of ambiguities can be reduced by narrowing the antenna beamwidth to attenuate the undesired signals. For range and wrong-side ambiguities the antenna dimension in the elevation direction would be scaled proportionally with frequency. As can be seen in (3) however, the location of the azimuth ambiguity is linearly proportional to the wavelength, thus, as wavelength increases, so does the angular separation of the ambiguity. For this reason the azimuth antenna dimension for spaceborne SAR is typically on the order of 10 m, regardless of the observing frequency.

Alternative approaches to resolving the presence of source ambiguities relies on data collection and signal processing methods for altering the viewing geometry such that returns from the desired target add coherently and those from the ambiguous targets decorrelate. Altering the PRF has such an effect on range and azimuth ambiguities [4]. We are currently investigating a new method for reducing azimuth ambiguities which splits the observing window into two

components (epochs). Within each epoch, we maintain a single PRF rate but change the timing of one epoch with respect to the other by half of a pulse interval. This effectively samples the target in both a real (I) and imaginary (Q) channel which can be reassembled in post processing to eliminate the first azimuth ambiguity.

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